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The influence of lime application in damaged pine forest ecosystems in Berlin (FRG): soil chemical and biological aspects†

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INTRODUCTION

It is commonly accepted that air pollutants play a major role in the development of tree damage and forest decline. But in many European countries the enforcement of pollution control measures is progressing only slowly, so that direct site amelioration may become necessary to prevent the forest ecosystem from collapsing.

Apart from forest management practices these measures could include lime and/or fertilizer applications.

Based on multi-year data from the Solling research project, Ulrich *et al.* (1979) were among the first to present a theory that explained the destabilization of forest ecosystems as a consequence of soil acidification caused by acidic precipitations. After identifying aluminium toxicity as the main stressor Ulrich (1986) recommends lime applications to restore buffering capacity and improve the Ca/Al ratio in the mineral soil horizons.

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The predominant effect of lime on microorganisms seems to be that a rise in pH value will lead to an increase in bacterial activity. All studies where the plate-counting technique has been used indicate that liming will increase the numbers of bacteria (Söderström 1984). Mai & Fiedler (1978) have reported that the species diversity and individual numbers of the saprophytic actinomycetes increased after liming.

The effects of liming on soil animals have been studied for a number of animal taxa. A summary of present knowledge is given in Persson (1988).

In this chapter, data about the effects of lime application on the litter decomposition process, the soil microorganisms and soil fauna and elemental fluxes are presented from the first three years of an interdisciplinary research project.

MATERIALS AND METHODS

Site description

The investigation area is located about 6 km southwest of the centre of Berlin in the 'Grunewald', a forest of 3000 ha within the city limits.

The soil is characterized by deep decalcification and acidification. The 5 cm organic forest floor is classified as a raw humus-like moder (C/N ratio 28–32).

The forest consists mainly of Scots pine (*Pinus sylvestris* L.) planted about 40 years ago and some oaks (*Quercus robur* L.) with black cherry (*Prunus serotina* Ehrh.) in the underbrush.

However, the pines show clear signs of damage expressed in needle loss, whereas the elemental status of needles shows no obvious nutrient deficiencies.

In April 1986, granulated dolomitic lime (6.1 t/ha) was applied to a $30 \times 80\ m^2$ plot in the study site, adjacent to a control plot of the same size. The liming was supplemented by a potassium fertilization (145 kg K_2SO_4/ha) to reduce the risk of Ca/K antagonism in root uptake.

Monitoring programme

Litter decomposition process

Litter containers, measuring 13.5 cm in diameter and 5.0 cm in height, were made of polyhpropylene tubes and closed by terylene nets with mesh sizes of 0.05 mm, 1.0 mm and 10.0 mm allowing the entry of different groups of soil taxa.

Each litter bag enclosed about 2.0 g of pine needle litter and 4.0 g of leaf litter from black cherry. The containers were randomly located in the litter layer of the forest floor of the study sites instead of the natural litter layer. Five litter containers of each type were collected on each of 11 sampling dates during a 2.5-year period.

Sampling of soil animals

In 1986–1988 the lumbricids were collected from the different soil horizons by hand-sieving. Two times a year (February and April) samples were taken.

Microbiological methods

The microbial activity in the different soil horizons was measured at 20°C by means of an O_2 uptake analyser (SAPROMAT) in the laboratory.

For the qualitative differentiation of microorganisms the plate-counting technique (counted in colony-forming units, CFU) was used (heterotrophic bacteria on nutrient agar, pH 7.2, +Actidion; saprophytic hyphomycetes and yeasts on malt agar, pH 5.5, + streptomycin/penicillin).

Terminology

The limed plots are always called Pd and the control plots Pk.

RESULTS

Liming effects on forest floor chemistry

The buffering effect of the dissolving granules led to a sharp pH rise from around 3.3 to 6.5 in the humus layer and to a slighter increase from 3.3 to 4.0 in the upper mineral soil layer during the first 2 years after treatment.

Liming effects on soil microorganisms (O and Ah layers)

Plate countings revealed that the number of heterotrophic bacteria growing on nutrient agar increased after liming and was maintained on the higher level (one order of magnitude in both horizons) for 3 years (Fig. 1).

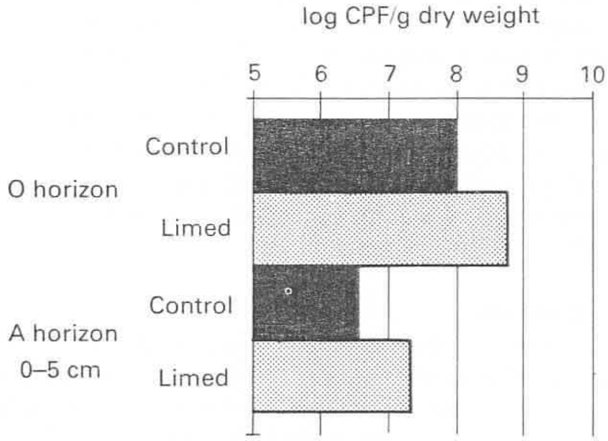

Fig. 1 — Total cell numbers of heterotrophic bacteria (colony-forming units per g dry weight, logarithmic) in samples taken from the O and A horizon 2–3 years after liming (mean values from three independent determinations).

On the other hand, merely qualitative changes at the species level but no quantitative change in the number of microfungi growing on malt agar were detected (Fig. 2). But in this context it has to be taken into account that plate counting mainly records spore numbers in the case of hyphomycetes.

Microbial respiration rate was measured to judge metabolic activities depending on energy metabolism of the aerobic microflora. Respiration activities in the two control plots differed somewhat from each other due to soil heterogeneity in the

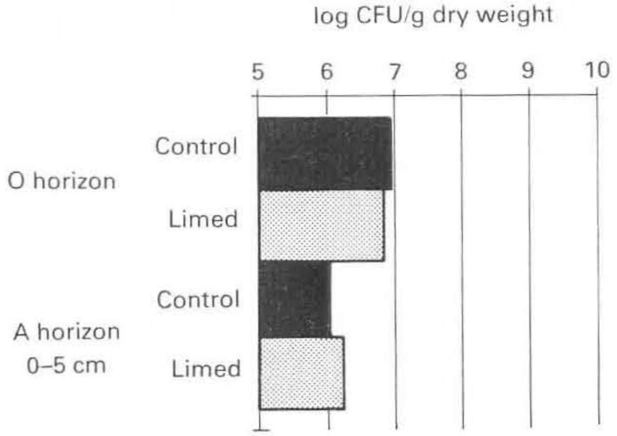

Fig. 2 — Total cell (spore) numbers of saprophytic microfungi in the same samples as used in Fig. 1 (mean values from three independent determinations, logarithmic).

Grunewald area. Nevertheless, the two plots treated with lime in 1986 and 1988, respectively, show a comparable increase of basal respiration rate (Fig. 3a, b). Though this effect appears rather insignificant with respect to the high standard deviation of the mean values, determination of potential respiration rates realized by the addition of glucose (ubiquitous energy source) revealed that the real effect of liming is much stronger. As exemplified in Fig. 4 there must be a remarkable increase of microbial biomass, which consequently is more strongly limited by substrate deficiency than in the control plot. The microorganisms are quickly activable by any suitable substrate supply.

Liming effects on the soil animals

Liming is clearly advantageous for the lumbricid species in the investigated forest stands (Fig. 5). Thus our studies shows that *Dendrobaena octaedra* (Sav.), a common species in coniferous forests, will increase very intensively in number after liming. However, this species never seems to penetrate below the Ah layer. Also *Lumbricus rubellus* (Hoffm.) and *Eiseniella tetraedra* (L.), two species of more fertile forest soils, increase in number after liming. These species are much larger in body size than *D. octaedra*, and may also burrow into the mineral soil with bioturbation activity.

Liming effects on the litter decomposition process

In the course of the experiments carried out in the forest sites using the litter container method the decomposition rates of black cherry leaf litter was determined. The results in Fig. 6 show that in the unlimed control initial litter decomposition was much faster than in the limed containers. The initial delay, lasting for about 12 months, may be due to some kind of adaptation of the microorganisms to the increased of pH value. With the improved chemical conditions in the soil due to the

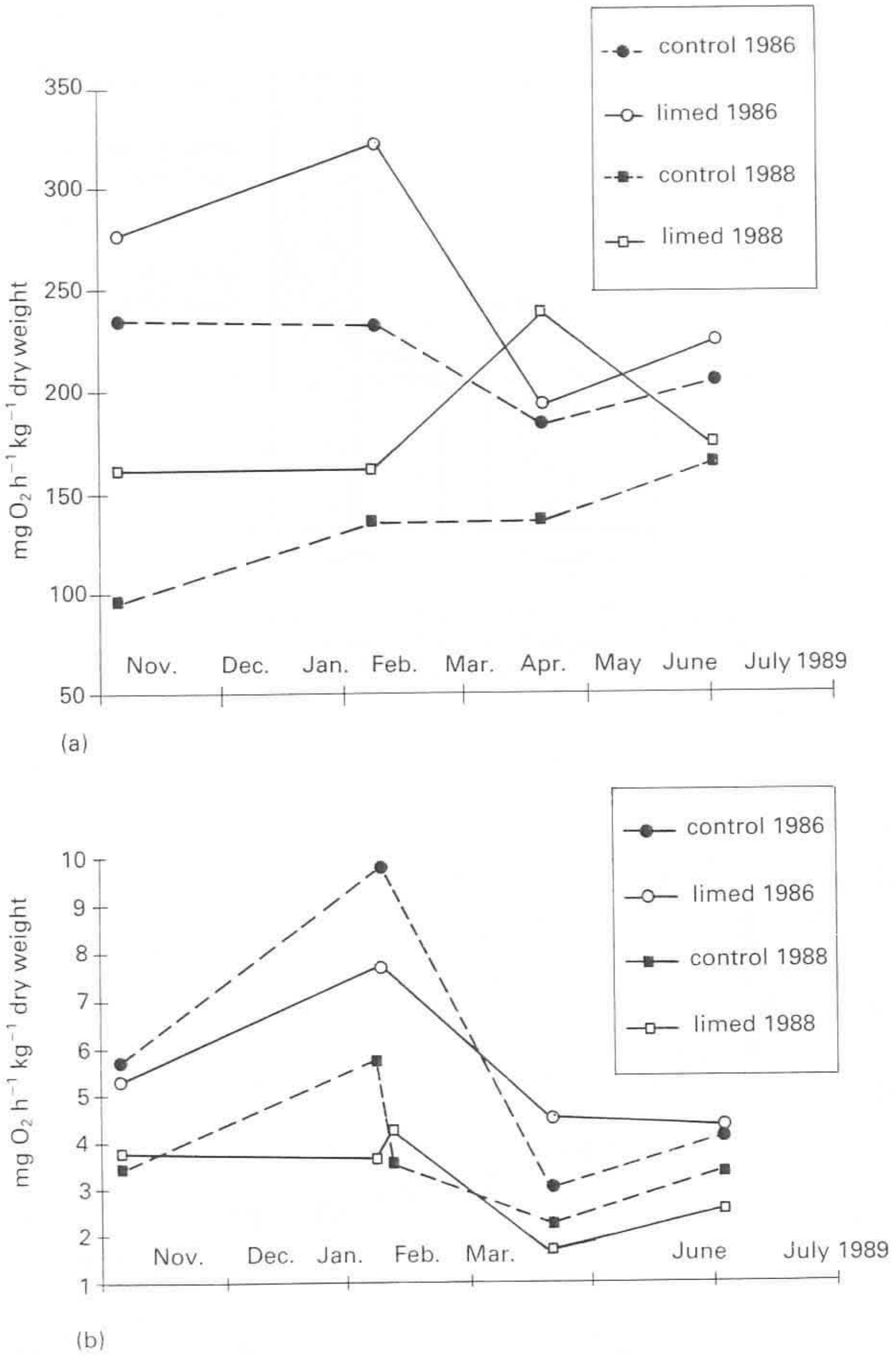

Fig. 3 — (a) Basal respiration rates in samples taken from the O layer of control plots and parallel plots limed in 1986 and 1988 respectively over the period from November 1988 to July 1989. (b) Basal respiration rates as in (a) but samples taken from corresponding A horizons (0–5 cm).

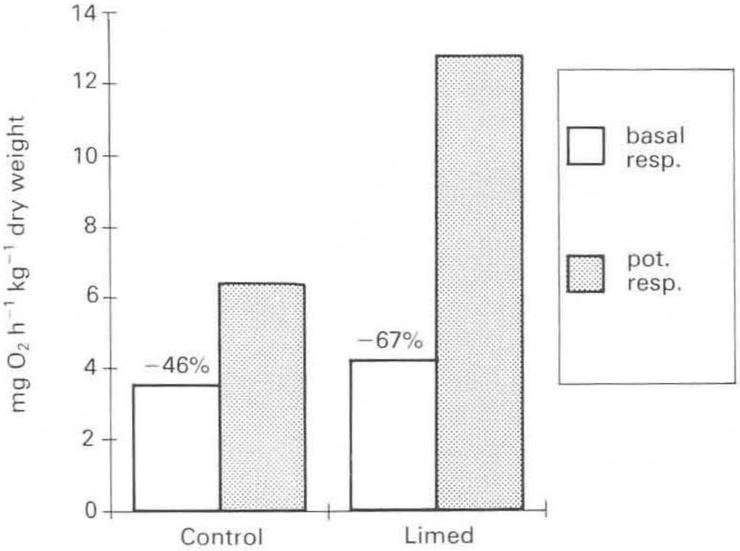

Fig. 4 — Basal respiration rates and glucose-induced respiration rates in samples collected in February from the A horizon (0–5 cm) of the plot limed in May 1988 and from the corresponding control plot.

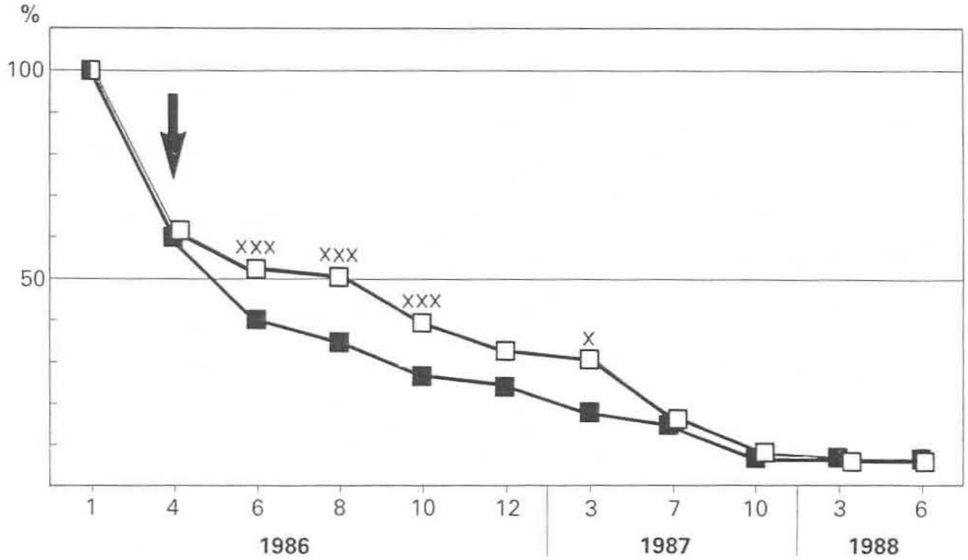

Fig. 5 — Remaining litter (%) of black cherry in litter containers (■=Pk; □=Pd; Student test xxx: $p<0.01$; x: $p<0.05$).

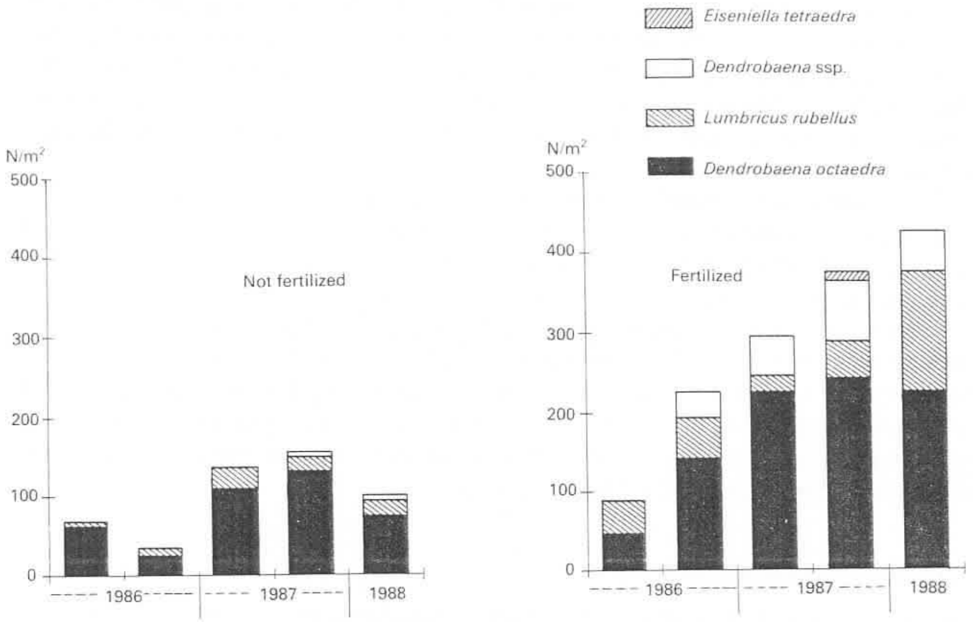

Fig. 6 — Lumbricid species in the forest stand.

higher activity of soil animals the availability of easily accessible carbon sources also increases and the initial inhibition of litter decomposition may compensate progressively. These results from the decomposition process do not seem comparable with the observed activation of the microorganisms due to liming (see above). It is taken into account that this investigation was carried out with the total humus layer, which is strongly acidified contrary to the freshly fallen litter.

DISCUSSION

It has been shown that the lime/fertilizer application has measurable effects on the forest soil within a short time period. Due to the buffering action of the lime, the input of acids from the litter layer into the humus layer has decreased greatly. This leads to the intended increase of exchangeable calcium and magnesium ions (Kreutzer & Bittersohl 1986), stabilizing the ecosystem according to Ulrich (1986).

Referring to soil organisms lime application leads to a sudden and drastic change of their environment. For the microflora, especially the saprophytic bacteria and microfungi concerned here, liming has various measurable effects. From the results it can be deduced that at least one part of aerobic bacteria well adapted to grow on nutrient agar increases in cell number by a factor of about 10. This higher level is maintained over at least 3 years, though the actual contribution of higher bacterial numbers and higher (potential) respiration rates to the overall mineralization proceses in the soil are limited by substrate availability and exhaustion of easily degradable organic components. This will not only affect humus quality (e.g. C/N ratio) but also reduce the quantity of organic mater. Consequences of this may become particularly relevant in poor sandy soils as in Berlin. Moreover, the stimulation of nitrification by raising the pH value and leaching of nitrate (Marschner, pers. comm.) in the same soil plots studied by us can also become hazardous for groundwater reserves.

While large soil animals, such as lumbricids, are clearly favoured by liming and respond with population increases, other soil animals, as for instance small ones still not documented today but well known from our own research and the literature, like some collembolans species, will decrease in numbers.

Today the causal relationship of such population changes are incompletely understood. Therefore, the consequences cannot be anticipated. The increasing abundance of large soil animals will probably result in a higher degree of mechanical breakdown and mixing of a litter material, which may also affect the qualitative and quantitative composition of the microbial community, and this for its part may have implications for microbial feeding soil animals.

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